Monthly Progress Report ARCHES PR-8

on

Antennas in Reconfigurable High-Impedance Electromagnetic Surfaces

covering the period

1 May 2000 to 31 May 2000

submitted to

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6 September 2000

1.0 Cost Summary

The actual expenses for the fiscal month of May 2000 were $42,517, and the cumulative actual expenses for the entire program through the end of May 2000 are 429,360. The amount funded as of month end is $663,500.

2.0 Man Hours Expended

The man-hours expended for this reporting period were 203. The cumulative man-hours expended are 2454. Shown below in Figure 1 is a summary of labor hours by labor grade, along with cost per labor grade for the month reported. Engineer 3 is the lowest paid labor grade working on this program, with program manager being the highest labor grade.

TITAN SYSTEMS CORPORATION
ATLANTIC AEROSPACE DIVISION

ARCHES - BAA 99-19
May 2000 **1555**

	Current Month		Cumulative	
DIRECT LABOR	**Hours**	**Cost**	**Hours**	**Cost**
Engineer 3	143	16,212	1,173	137,709
Engineer 4			262	33,458
Engineer 5	47	8,228	829	148,269
Engineer 6			10	1,941
Program Manager/Engineer	14	3,489	181	45,688
	203	**27,929**	**2,454**	**367,065**

	Current Month	Cumulative
ODCs with Material Handling Fee	**Cost**	**Cost**
Materials	4,100	12,600
No Fee Subcontractor	16,454	37,646
Subcontractors	-7,950	
	12,604	**50,246**

	Current Month	Cumulative
OTHER DIRECT COSTS	**Cost**	**Cost**
In-house Cosultants		
Miscellaneous	561	1,636
Rental Materials		
Travel	1,423	10,414
	1,984	**12,049**

	Current Month	Cumulative
TOTAL PROGRAM COST	**42,517**	**429,360**
Committments		33,070
TOTAL PROGRAM COST + Committments		**462,430**
Budget At Completion		**2,500,564**

Figure 1. Summary of the May costs by labor grade and ODCs.

3.0 Schedule Status

During this reporting period, May 2000, the following tasks where pursued: Task 1.1 – Passive Broadband AMC Dev., Task 2.1 – Identification of Desired Equivalent Media, Task 2.2 – Fast Solver Development, and Task 4.0 – Program Management. Refer Figure 2 below for the program schedule.

WBS	Task Name	Budget	Spent
0	ARCHES	$2,500,564	$429,360
1	Integrated Ground PlaneTechnical Dev.	$1,381,843	$279,692
1.1	Passive Broadband AMC Dev.	$325,981	$264,191
1.2	Reconfigurable Bandgap AMC Dev.	$545,363	$15,501
1.3	Switchable Element Development	$397,444	$0
1.4	Electronic Controls Development	$113,055	$0
2	Computational Tool Development	$604,994	$69,802
2.1	Identification of Desired Equiv. Media Prop.	$78,686	$45,240
2.2	Fast Solver Development	$41,650	$16,418
2.3	Realizability of the Desired Effective Medium	$131,605	$0
2.4	Spectral Domain Code Development	$252,408	$0
2.5	ASU Reports and Meetings	$57,311	$8,145
2.6	Transition Plan to Commercial Software	$43,334	$0
3	Array Demonstration	$286,774	$0
3.1	Decade (.2-2 GHz) Lab Demo	$286,774	$0
4	Meetings and Reports	$226,953	$79,866
4.1	TIMs	$93,243	$58,335
4.2	Monthly Status Reports	$37,755	$21,042
4.3	Annual Technical Reports	$95,955	$0

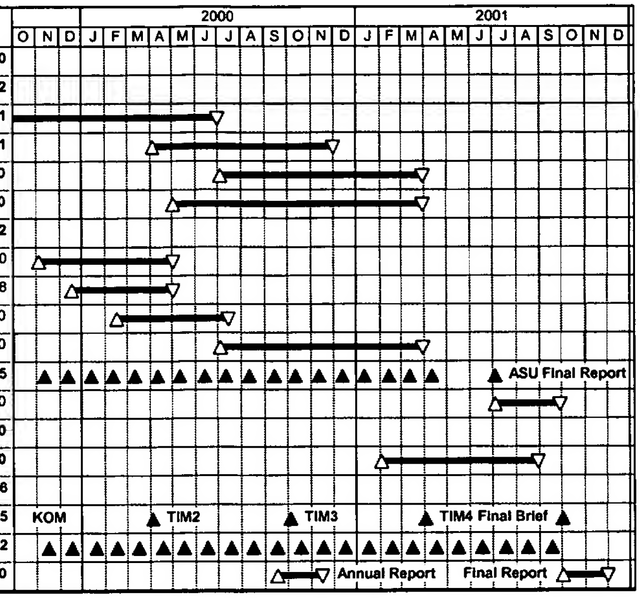
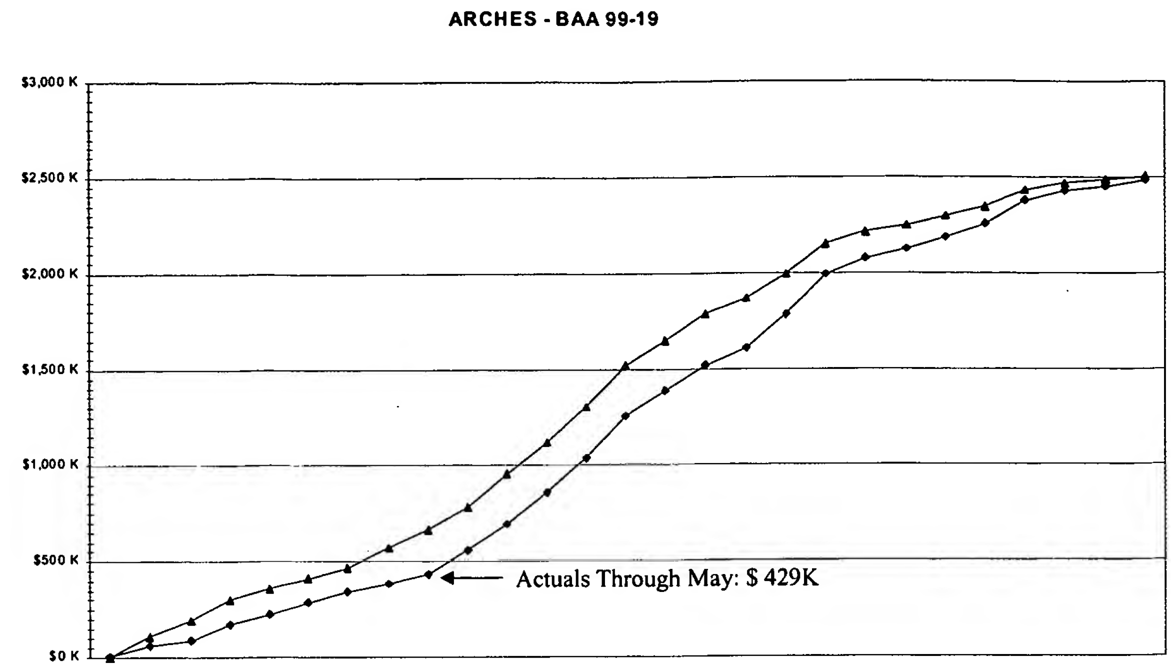


Figure 2. ARCHES program schedule, budgeted costs, and spending through May 2000.

A breakdown of planned budget for each task is given in Figure 2 for each line item. The second column on this chart shows the cumulative amount spent per line item. The chart shows we are approximately 81% spent on task 1.1, 57% spent on task 2.1 and 39% spent on task 2.2 (spending on other technical tasks is trivial).

The burn curve is shown below in Figure 3. It shows we are underspending the plan. Both Atlantic Aerospace and ASU are below their projected spending levels.



	S-99	O-99	N-99	D-99	J-00	F-00	M-00	A-00	M-00	J-00	J-00	A-00	S-00	O-00
LRE (Act thru May 00)	$5	$62	$92	$170	$229	$289	$345	$387	$429	$557	$692	$856	$1,040	$1,256
Budget thru Fee	$0	$109	$193	$301	$354	$410	$466	$571	$667	$782	$951	$1,122	$1,306	$1,519

	N-00	D-00	J-01	F-01	M-01	A-01	M-01	J-01	J-01	A-01	S-01	O-01	N-01
LRE (Act thru May 00)	$1,389	$1,521	$1,606	$1,777	$1,991	$2,074	$2,121	$2,182	$2,249	$2,378	$2,426	$2,451	$2,475
Budget thru Fee	$1,650	$1,783	$1,867	$1,992	$2,149	$2,208	$2,244	$2,290	$2,339	$2,431	$2,466	$2,483	$2,501

LRE (Act thru May 00) Budget thru Fee

Figure 3. May 2000 Burn curves: actuals (blue) and budget (red).

4.0 Technical Progress

Task 1.1 Passive Broadband AMC Development: The goal of this task is to design and demonstrate a passive AMC whose surface wave bandgap and impedance bandwidth is an octave in bandwidth for a structure whose electrical thickness is $\lambda_o/50$ at its resonant frequency ($f_o = c/\lambda_o$). In order to achieve this performance, we have determined that materials with permeabilities (μ') of about 5 and permittivities (ε') around 10 with low loss up to 2 GHz are necessary. Note: the derivation of these requirements is contained in the six-month technical interchange meeting, TIM-2, delivered April 10th, 2000.

As reported in TIM-2 and in the previous monthly status report, we have implemented a multi-threaded approach towards achieving these material requirements. This approach includes:

- **Unaligned Barium-Cobalt Hexaferrite Tile approach:**

  - Barium-Cobalt Hexaferrite - $Ba_3Co_2Fe_{24}O_{41}$ (also known in short hand as Co_2Z) has been demonstrated previously (Smit and Wijn, Ferrites, 1959, John Wiley & Sons). This approach is therefore deemed relatively low risk and is our baseline approach.

- Tom Countis of Countis Labs is working this task. He is in the process of firing several test samples this month. Also, this month we helped him implement his coaxial resonator test set-up for testing these materials. We have formulated a solution and sent him a Mathcad program, which relate resonance frequency to permeability of the test sample in the resonator.

- **Barium-Cobalt Hexaferrite Powder in Elastomeric Binder approach:**

  - This approach is a risk/cost reduction alternative to the solid Co_2Z tiles.

  - Ron Ekdahl of Praxair is one of the vendors providing Co_2Z powder. This month he worked through some production problems and delivered his first samples of this material. X-ray diffraction implies that the crystal structure of his powder is consistent with Co_2Z. Also, he is achieving roughly 3-micron particle sizes – which is slightly larger than desired.

  - Arun Ranade of Particle Technologies is a second vendor producing this powder. Particle Technologies' fabrication method is Aerosol Spray Pyrolysis, which involves vaporization of a liquid solution using a piezoelectric membrane modulated at 1.7 MHz. This method does achieve particles with spherical shapes that are approximately 1-2 microns in size (see scanning electron microscope (SEM) image in the figure below).

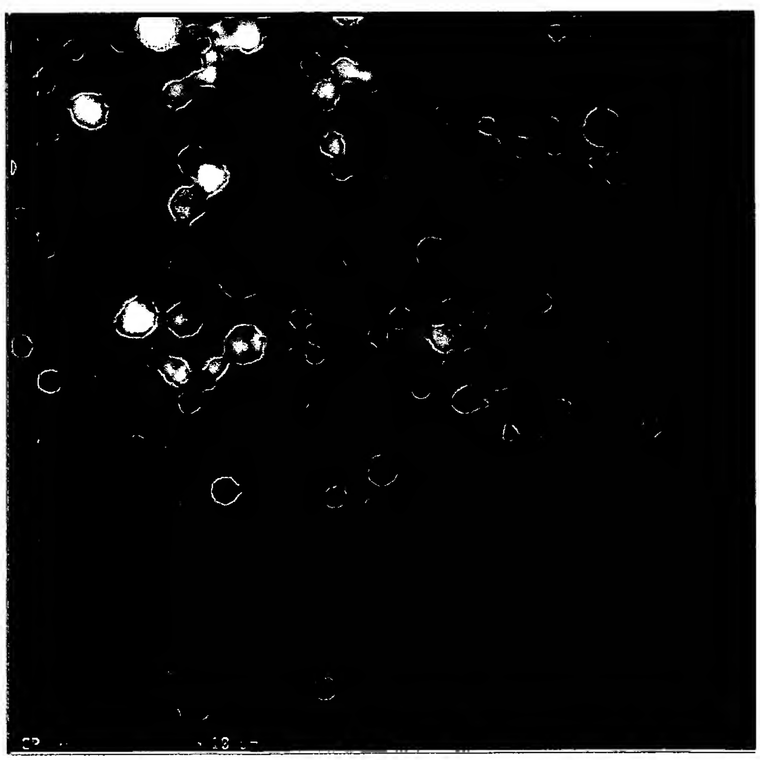


Figure 4 – SEM image of Particle Technologies Co_2Z Powder

- **Nickel-Iron Permalloy Nanoflakes in Elastomeric Binder approach:**

  - This approach is a somewhat high-risk alternative to the solid Co_2Z tiles. The approach is to use conventional 80/20 Nickel/Iron permalloy nanoflakes in a lightweight binder that is partially filled with microballoons to occupy volume.

  - Rick Johnson of R&F Products is procuring the nanoflake material from Novamet. He has not received this material yet. R&F products will be mixing the permalloy material (as well as the ferrite powder materials) with the elastomeric binders and performing RF testing in a coaxial airline fixture to determine the permittivity and permeability of the samples.

Task 2.1 Identification of Desired Equivalent Media Properties: The purpose of this task is to determine analytically the optimum permittivity and permeability tensors for a two layer conductor-backed substrate, which yields broadband AMC performance. The scope of this task has expanded to include transverse resonance modeling to predict surface wave bandedges, and to include an investigation of commercially available magnetic materials to support a Task 1.1 demonstration of a broadband AMC. A bulletized summary of the technical progress achieved this month is presented below.

- The analysis of the surface wave properties of a two layer uniaxial anisotropic medium has been redone and a hardcopy of the derivation is being sent. This work was motivated by unusual test results on the 2:1 bandwidth structure built at AAEC. One of the important findings in this rework is the need to go away from the King and Park formalism for the case of materials with loss.
- Structures with 2:1 reflection coefficient bandwidth are being studied explicitly. One of the findings is that for such wide bandwidths the natural surface wave cutoff bandwidth is less than 2:1.
- The importance of realistic loss in these structures is shown analytically. A finite amount of electric loss in the via array medium kills off all higher guided TM modes at almost no penalty to antenna gain.
- The Reaction Theorem was used to estimate the antenna patterns of a bent monopole on an AMC.
- Also motivated by that experience is the ongoing development of a general-purpose program in MathCad incorporating these results for the analysis and design of proposed AMC structures.
- The spectrum of guided surface waves that can be supported by an arbitrarily dispersive grounded slab continues to be investigated to ensure that backward surface waves are not excited by the new AMC designs being proposed

Task 2.2 Fast Solver Development: The purpose of this task is to develop quasi-electrostatic fast Laplace solver algorithms to analyze candidate structures. The results of this effort will be a numerical approach able to obtain very fast analysis of configurations which would otherwise require many hours to individually analyze using full-wave Maxwell solvers. During this month, the Laplace solver has been improved and is being tested against canonical cases to establish its accuracy and range of applicability.

Task 4 Meetings and Reports:

Very little time was spent on this task during the month of May.

5.0 Plans for the Next Month (June 2000)

In August period, we will again focus on progress related to of artificial magnetic materials with the goal being an octave bandwidth AMC demonstration. Also, we plan to finalize the design work associated with the reconfigurable AMC and begin the fabrication and test stage. Also, we will continue to work under task 2.1 towards identification of desired media properties. Specifically, the goal is to find those properties of materials which inhibit surface wave propagation.